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Shore Protection Project Life Cycle Evolution

&

Economic Consequences

Shore Protection Project Performance & Economic Consequences

Formulation Requirement

Projects must be cost-justified

- Benefit-cost analysis
- Risk and uncertainty included in analysis

Relevant Issues / Parameters

- Environmental Forcing
- Morphology Evolution
- Infrastructure Inventory & Valuations
- Infrastructure Damage Functions

Goal: *Integrate meteorology, coastal engineering, and economics*

Beach-*fx* Features

Probabilistic Storm Generation

Impact of Storms on Beaches and Structures

- Beach morphology change (profile)
- Erosion, wave, and inundation damage

Long-term and Project-induced evolution

- Beach morphology change (planform)
- Vulnerability

Management Measures

- Planned and Emergency Beach Nourishment
- Infrastructure recovery rules

Beach-*fx* Development Approach

Transparency / Portability

- Generalized Architecture
- “glass-box”

Ease of Use

- Intuitive, familiar interface to data and model
- GIS linkages

Architecture

- Access Database
- Graphical User Interface
- Monte Carlo Simulation

Goal: *Broadly applicable, technically sound, non-proprietary models*

Beach-*fx* Incorporating Uncertainty

Choose input data to treat as uncertain

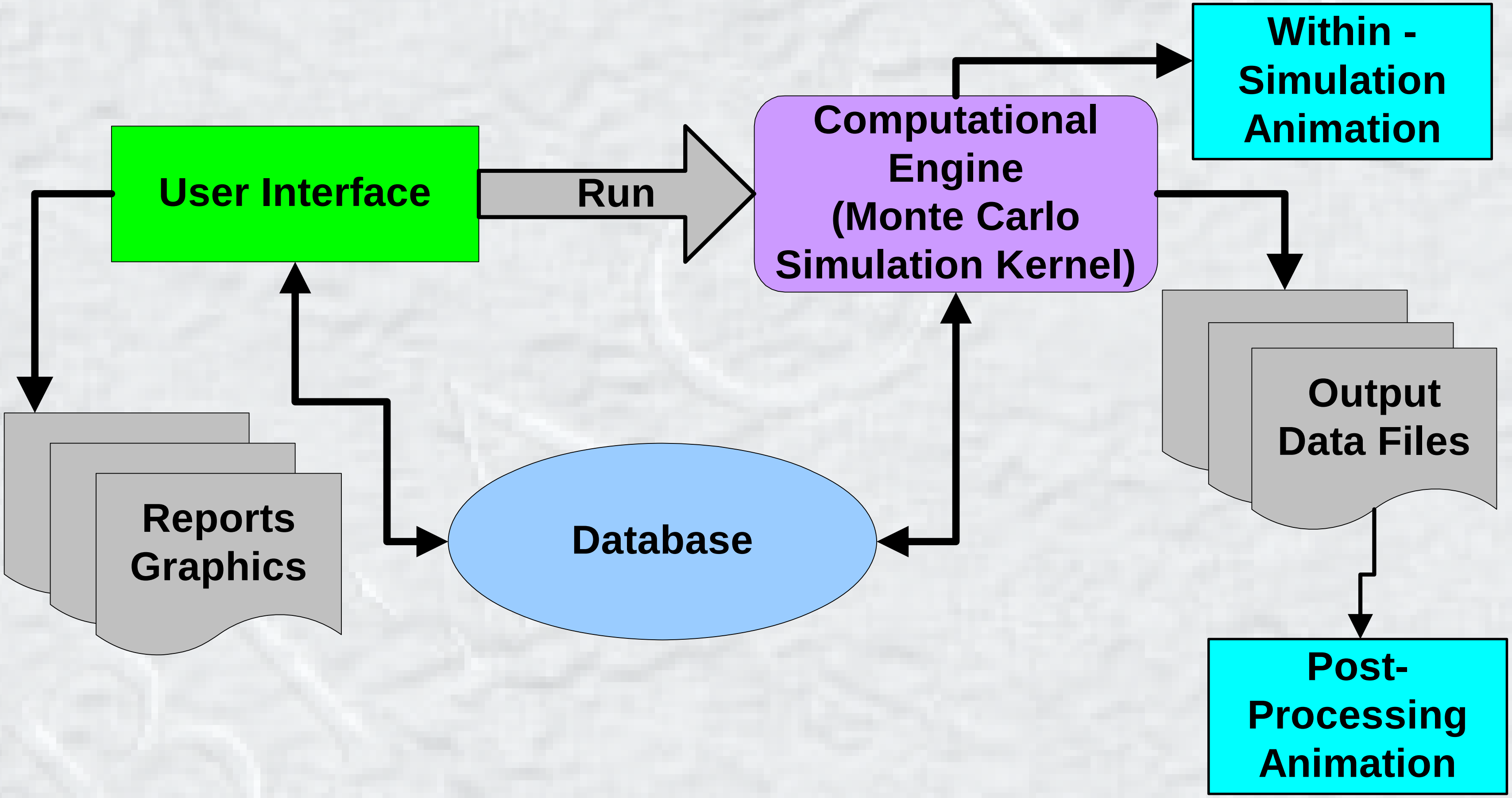
- Storm occurrence and intensity
- Structure parameters (elevations)
- Structure and Content valuations
- Damage Functions

- Define distributions of uncertainty
  - Historically-based (storms)
  - Triangular (structure parameters/damage functions)

- Run multiple iterations over analysis life cycle

- Obtain overall statistics based on iterations

Beach-*fx* Data Driven Architecture



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Event-based Monte Carlo Life Cycle Model

Life Cycle

- number of years = iteration = series of events
  = economic analysis period (e.g., 50 years)

Event

- Behavior/Action at specific time in life cycle
  - ✓ Random (storms, structure failures) ☞ dune/berm evolution
  - ✓ Fixed (monthly, weekly, daily) ☞ planform evolution
  - ✓ Relative (events triggered by previous events) ☞ management/process
- Time moves forward, event to event

At each event

- Simulate behavior, record activity, accumulate statistics

Each life cycle, record summaries

Each run, generate statistics on life cycle results

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Environmental Forcing

Historical and Plausible Storm Events

- ID significant historical Tropical & Extratropical storm events
  - ✓ DRP database
- Extract storm surge hydrograph
- Generate equilibrium tidal information
  - ✓ DRP/CIRP tidal constituent database
  - ✓ Develop tide elevation CDF and sample to extract three statistically representative tidal ranges (low, mean, high)
- Combine storm surge hydrograph with representative cosine tide aligning peak surge at 4 phases of the tide signal.
- Develop wind waves for each historical storm
  - ✓ WIS Database
  - ✓ WISWAVE handcrafted hindcast

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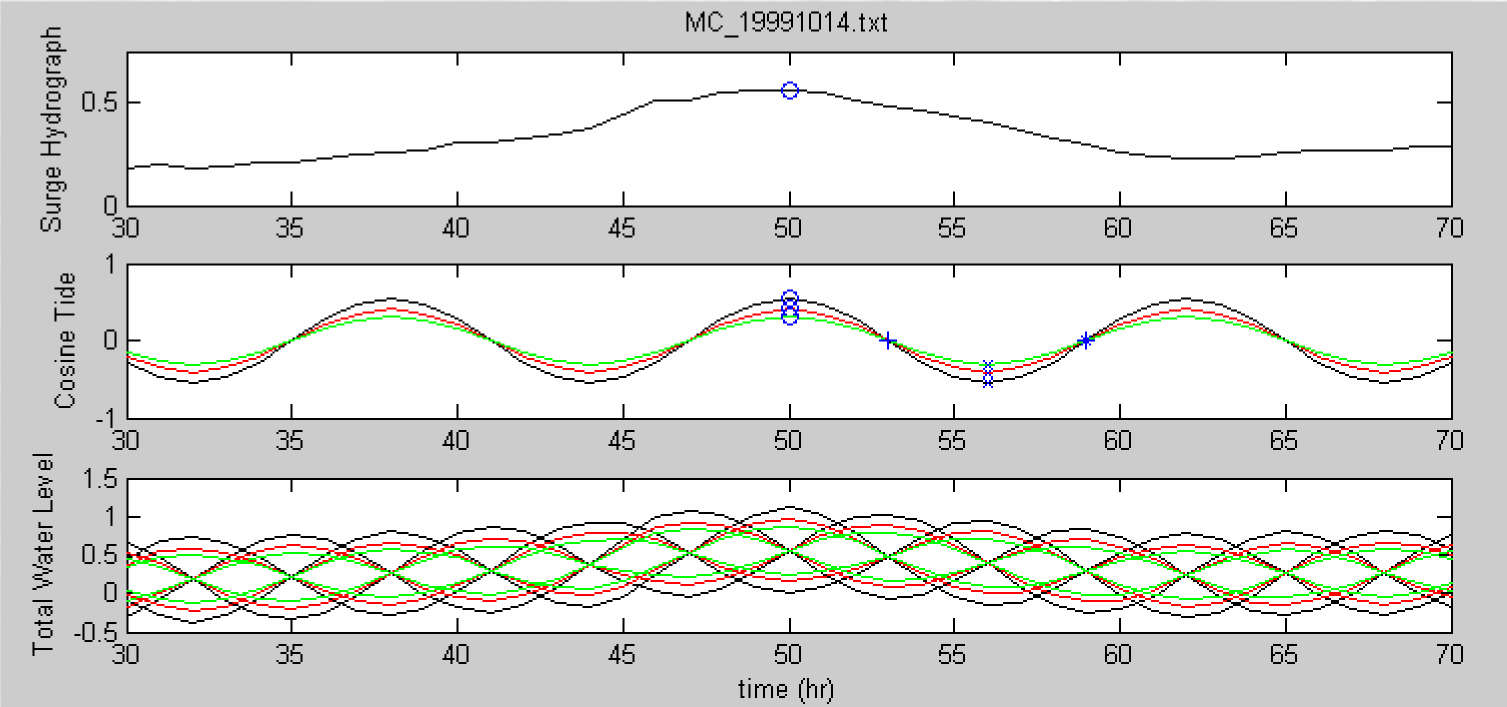
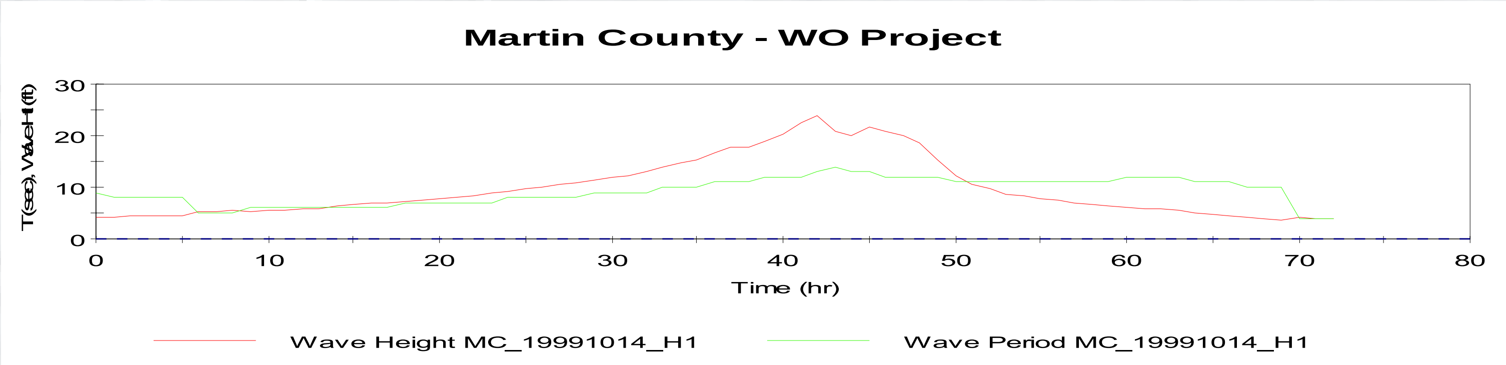
Environmental Forcing





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Morphology Evolution

Temporal variations in coastal geomorphology occur in

- Cyclic patterns (seasonal) ☒
- Non-cyclic events (storms) ☑
- Longterm trends (planform evolution) ☑

Non-cyclic events are viewed as short-term (mostly recoverable) storm-induced processes that result in beach profile changes.

Long-term trends give rise to historical shoreline change and (non-recoverable) beach planform changes. Can be historical or project induced (spreading-out of beach nourishment).

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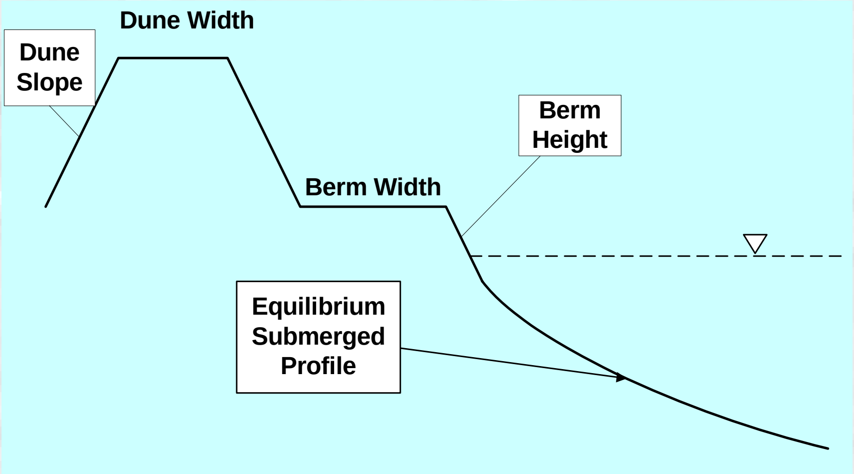
Morphology Evolution

Beach evolution within the Monte Carlo model relies a pre-computed Shore Response Database (SRD). The SRD contains estimated storm-induced changes in parameters that define a simplified beach profile.

- Berm width
- Dune height
- Dune width
- Upland width



The SRD contains long-term shoreline change (applied shoreline change rates and estimated project-induced shoreline change.

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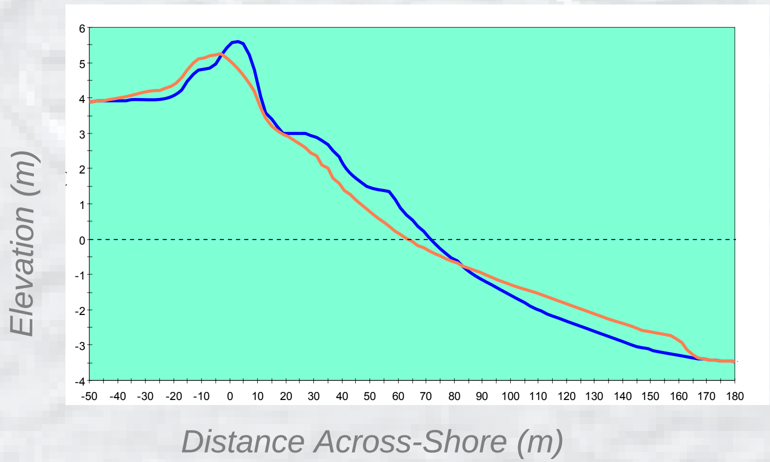
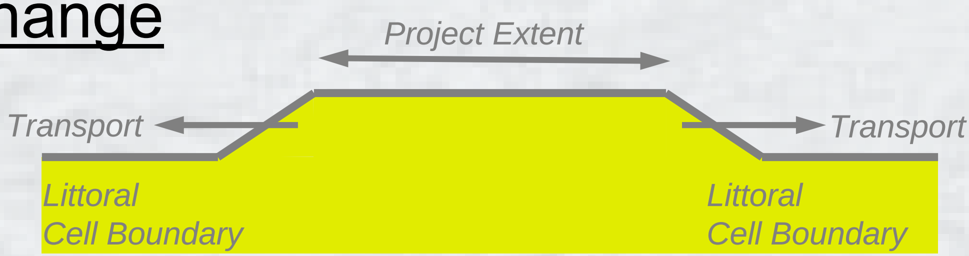
Modeling Coastal Morphology Change

<u>Beach Profile Change</u>
Time scale: short-term
Process: cross-shore transport
Tool: SBEACH



<u>Shoreline (Planform) Beach Change</u>
Time scale: long-term
Process: longshore transport
Tool: GENESIS



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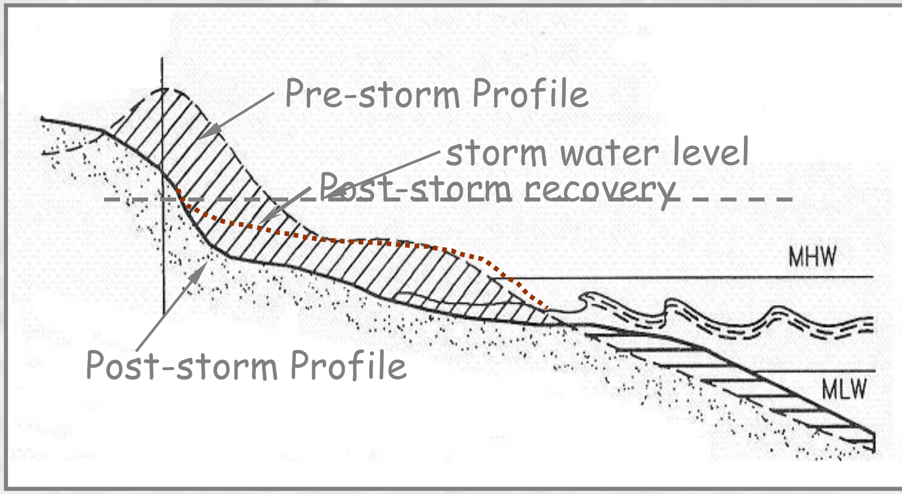
Modeling Beach Profile Change

Beach Profile Response to Storms:

Post Storm

- Erosion of berm
- Scarping of dune face
- Dune erosion
  - ✓ lower crest elevation
  - ✓ landward displacement



Recovery

Berm width and scarping low on the dune face is restored to near pre-storm conditions during weeks/months following storm passage.
(No predictive capability for this process).

Major dune erosion does not recover.

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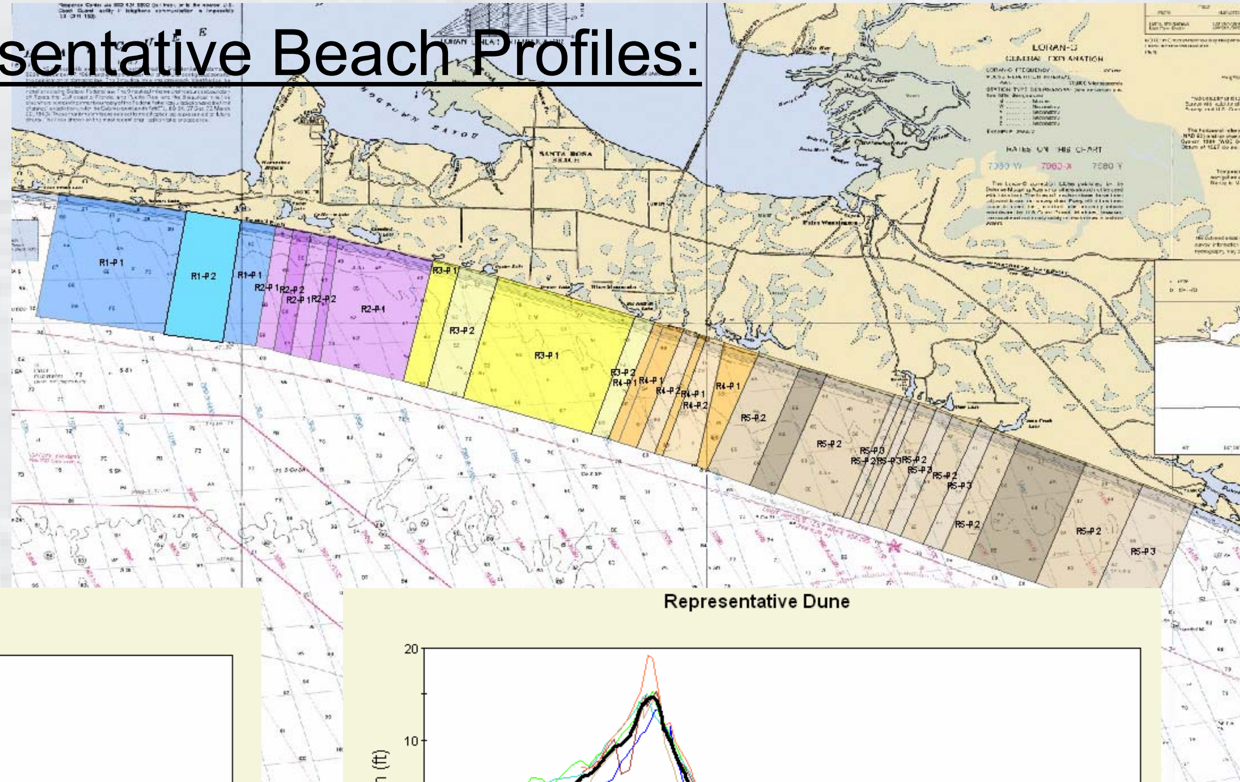
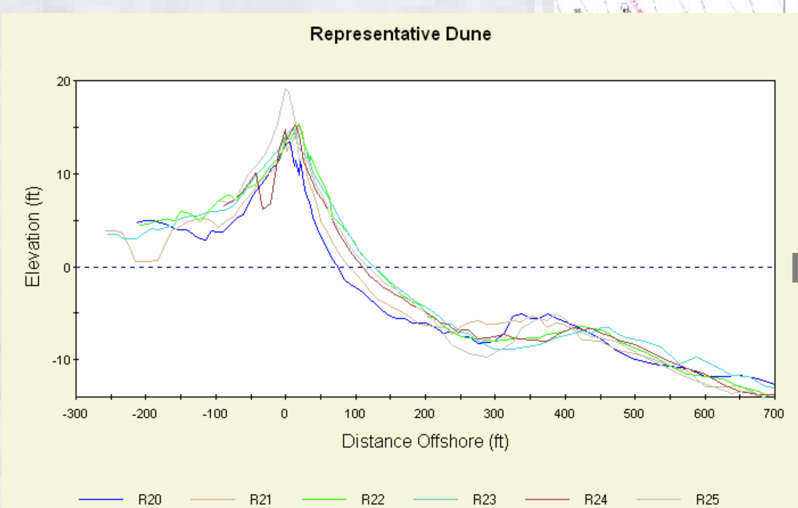
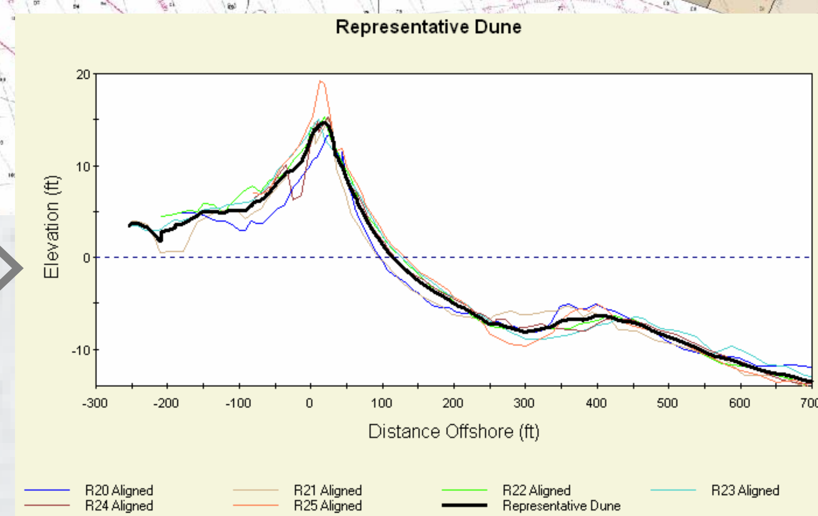
Characterization of the Study Area



<u>Morphologically Representative Beach Profiles:</u>

Representative beach profiles are our best estimate of the beach profile condition at the occurrence of any future storm, emphasis on the submerged profile





representative dune

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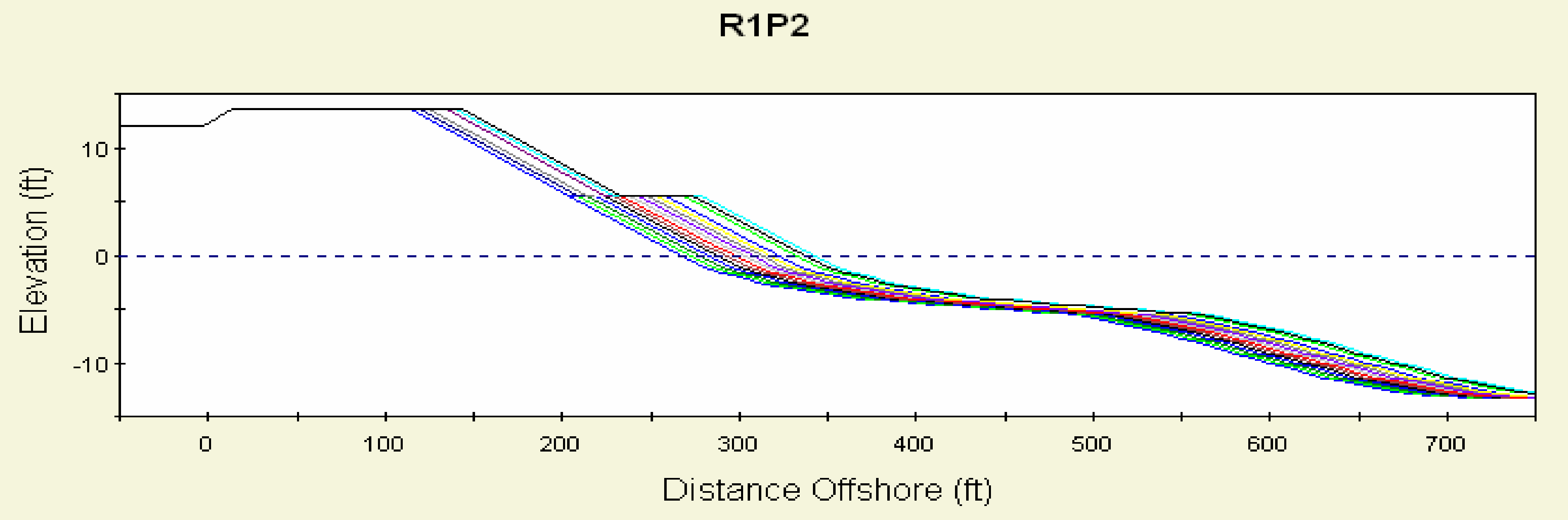
Executing SBEACH Simulations

Populate Shore Response Database:

- The SRD provides estimates of beach profile response for all potential future beach profile conditions

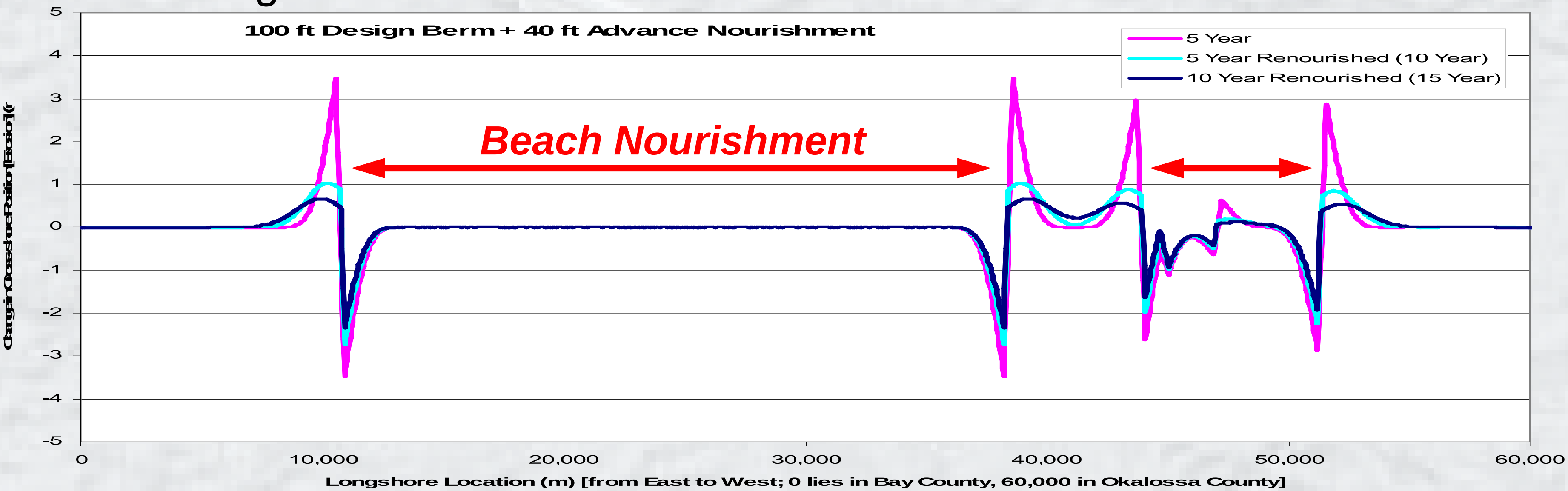
- Simulate beach profile response to suite of historically-based plausible storms for range of anticipated future dune and berm configurations.



Beach-*fx*
Execute GENESIS Simulations

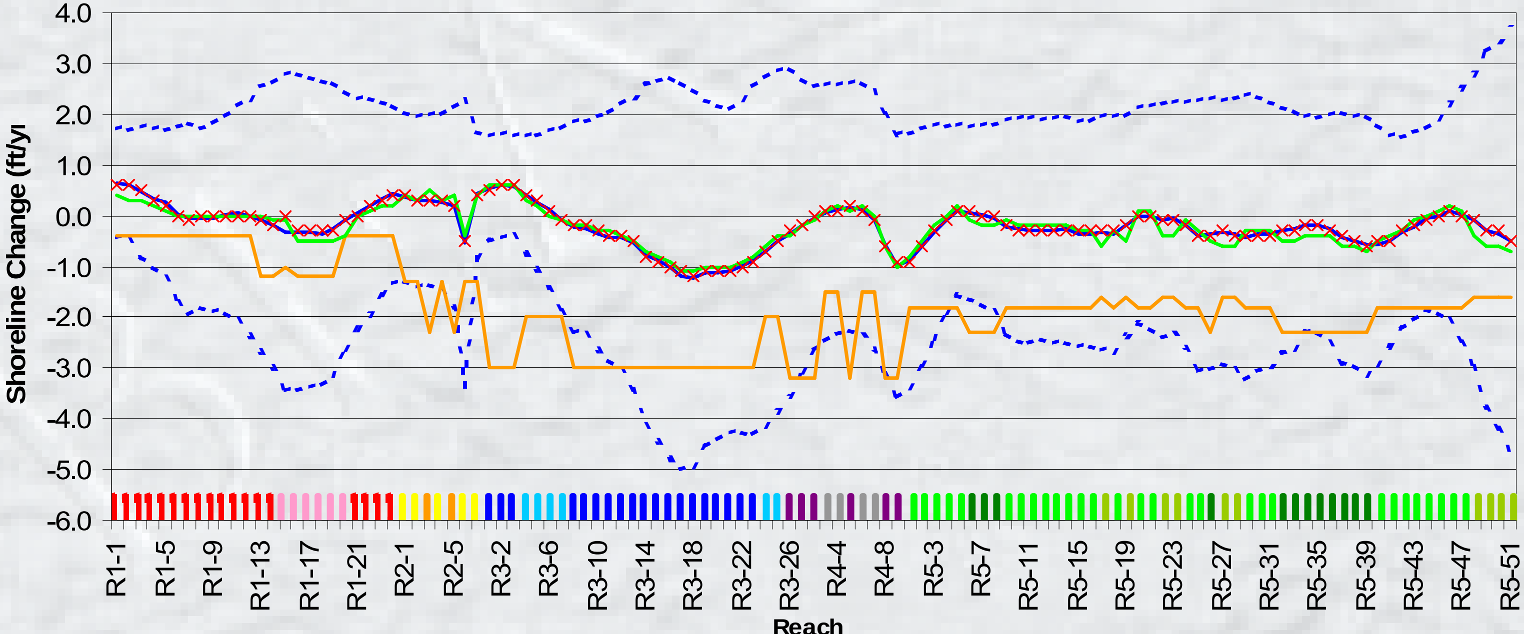
Populate Shore Response Database:

- The SRD provides estimates of shoreline change and project-induced beach planform change.
- Within Beach-*fx* an ‘applied’ shoreline change rate is developed as part of the calibration process.
- The evolution of beach nourishment projects is simulated with GENESIS and the estimated time dependent project-induced shoreline changes are stored in the SRD.



Beach-*fx* – Calibration Strategy

- The average of multiple without-project life cycle simulations should return the historical rate of shoreline change (+/-).
- Determine average rate of shoreline change produced by storms with specified planform shoreline changes set to zero.
- Adjust 'applied' shoreline change rate such that the combination of storm-induced and applied shoreline change return, on average over multiple life cycle simulations, the historical rate of shoreline change.



Beach-*fx*

Model Behavior for a Storm Event

For Each Storm Event (from Generated Sequence)

- Process all active profiles
- Process all active reaches represented by each profile

For Each Reach

- Pre-storm Berm Width / Dune Width / Dune Height
- Best match in SRD (Lookup Profile)
  - Closest Dune Height (subset)
  - Closest Berm Width (subset of subset)
  - Closest Dune Width (single response)
- Obtain lookup Responses from SRD
  - Berm width, dune width, and dune height change
  - Wave & Water level profiles, Erosion profile (for damages)

Apply Profile Evolution Algorithm to Pre-Storm to obtain Post-Storm Profile

Beach-*fx*

Model Behavior for a Storm Event

Recognize that the simplified profile does not exactly correspond to predicted beach profile shape so lookup changes can not always be directly applied.

- Berm width reduction, dune width reduction, dune height reduction, upland width reduction

Scarping

- recoverable – low on the dune face
- non-recoverable – scarping high on dune face

Apply Recovery to Post-Storm profile to get Post-Recovery profile (only berm width recovers)

- Pro-rate recovery to complete at user-defined interval (global)

Beach-*fx*
Geographical Hierarchy

Reach

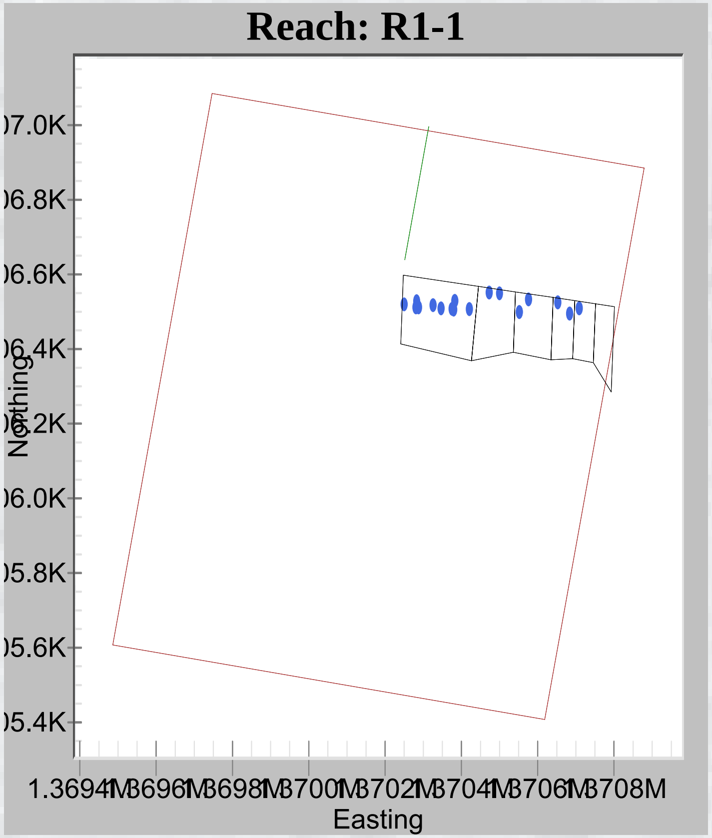
- Contiguous along shore
- Represented by common morphologic profile
- SBEACH cross-shore reference

Reaches contain Lots

- Represented as quadrilaterals

Lots contain Damage Elements

- Representative point, length & width



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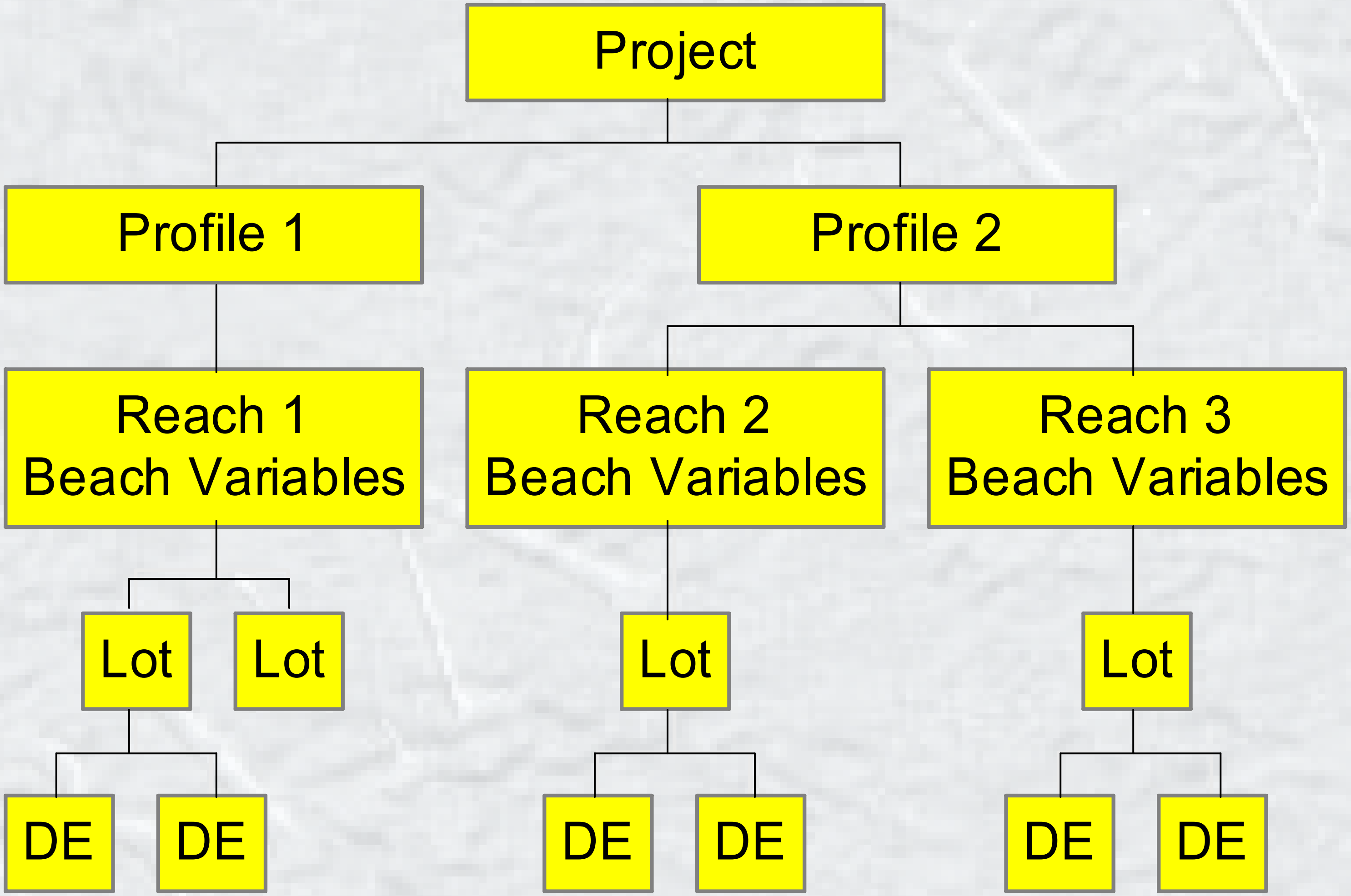
Project Hierarchy



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Damage Element Data

Location

- Bounding Rectangle / Representative Point (Geodetic coord.)
- Representative Elevation (distribution)
- Ground offset (distribution)

Type

- Usage (SFR, MFR, etc.)
- Foundation / Construction / Armoring
- Linear (walkover structures)

Economic

- Structure and Content Value (distribution)
- Rebuilding allowed?
- Time to rebuild (distribution)

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Damage Calculations

Damage Functions

- IWR workshop / Expert elicitation
- Single Family Residential

For each combination

- Element type (house, walkway, pool, etc.)
- Damage type (erosion, wave, inundation)
- Foundation type
- Structure / Contents

Define 3 Curves of

- **%Value Damaged = f(damage driving parameter)**
- Max, Min, Most likely
- Combined impact (relationship)

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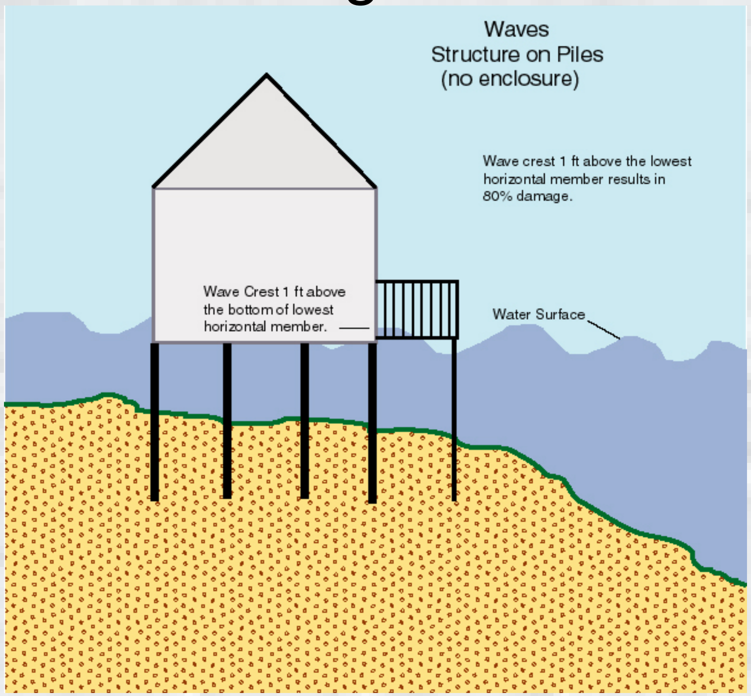
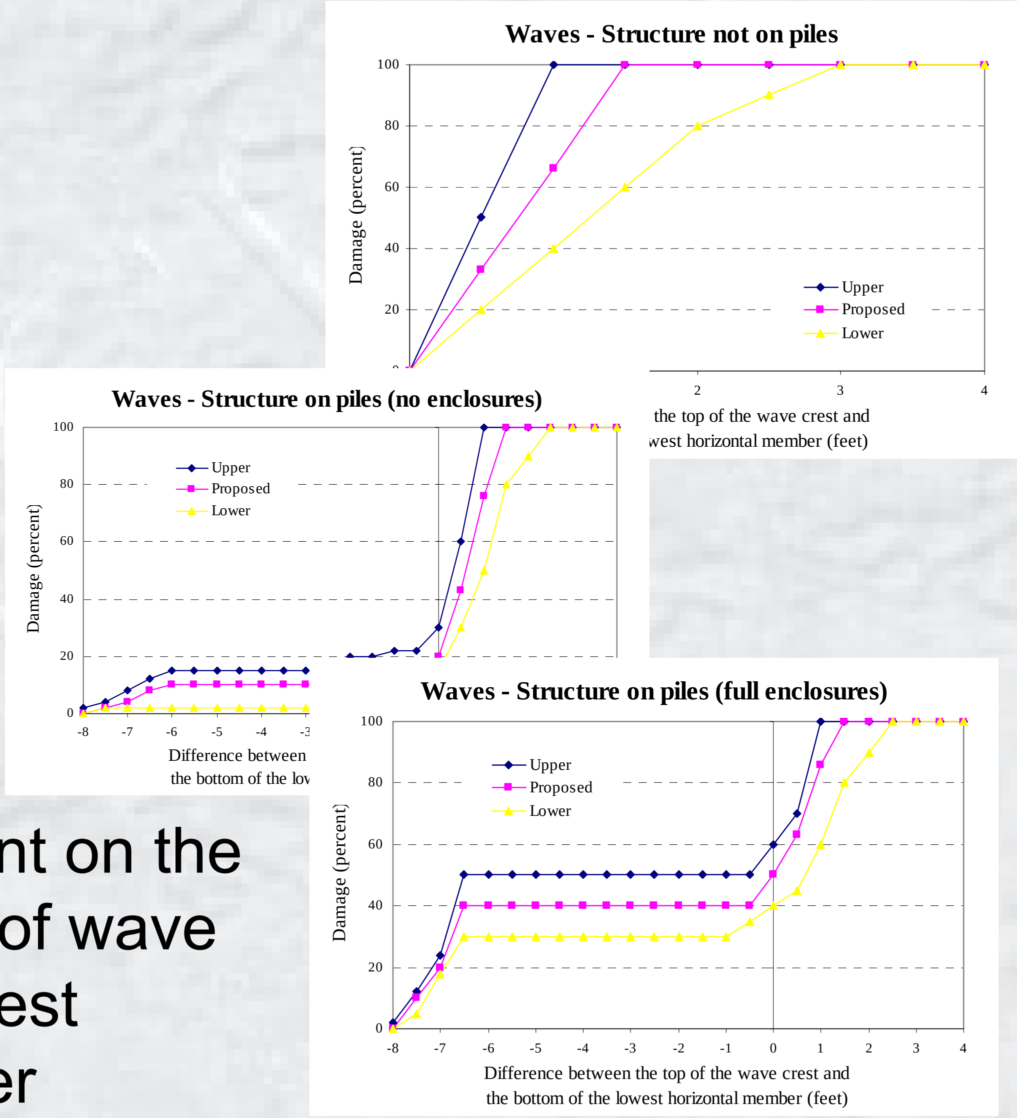
Damage Functions

Wave Damage





Extent of damage dependent on the difference between the top of wave crest and bottom of the lowest horizontal structural member

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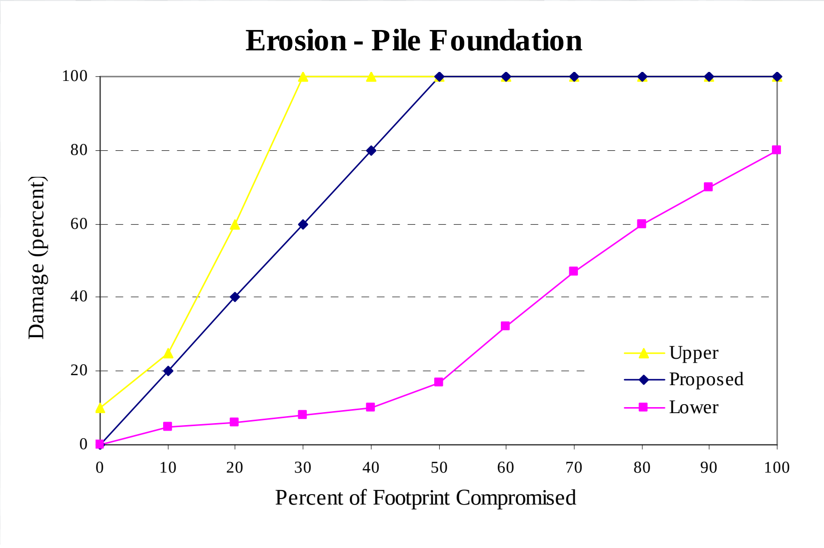
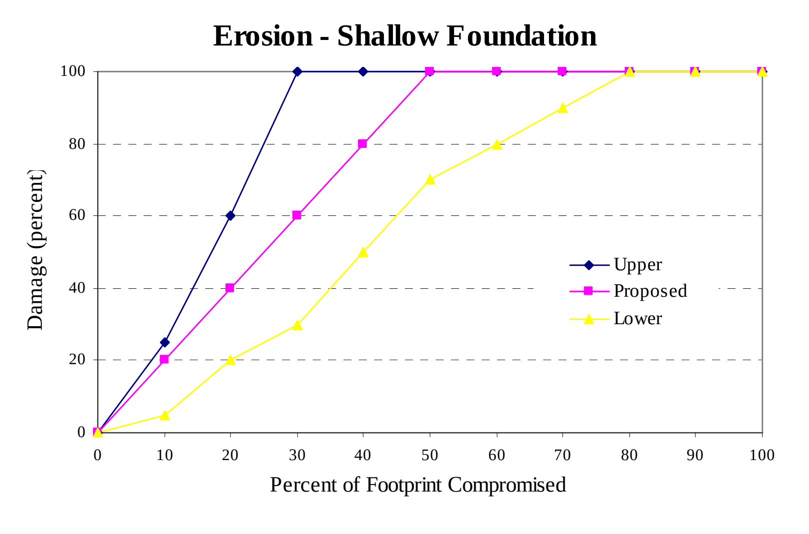
Damage Functions

Erosion Damage

Extent of damage for structures with shallow and pile foundations was dependent on the “percent of footprint” compromised.





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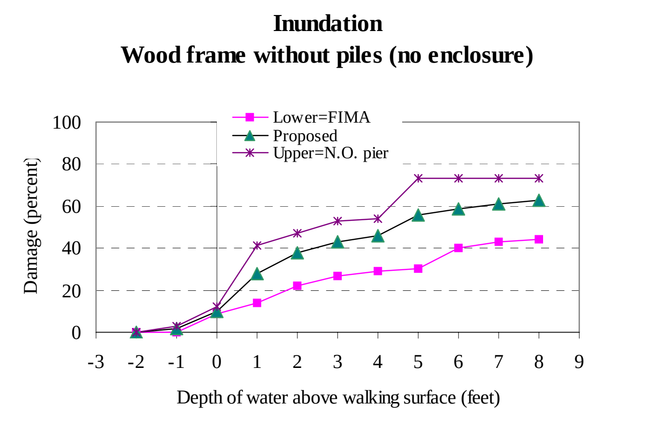
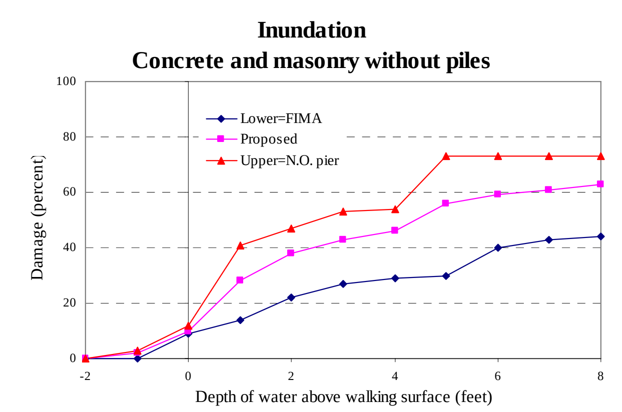
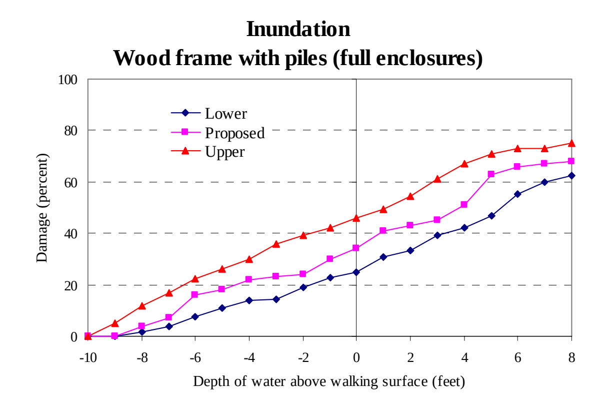
Damage Functions

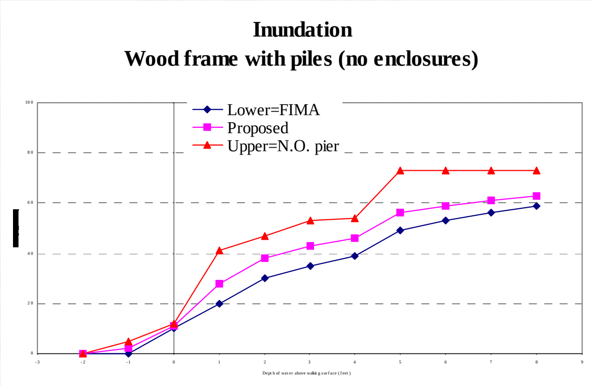
Inundation Damage

Extent of damage dependent on depth of water above the walking surface of the lowest main floor.









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Damage Calculations

Damage Driving Parameter is specific to damage type

- Inundation / Wave = water level – 1st floor elevation
- Water level = max water elevation + setup + ½ max wave height)
- Erosion - % of footprint compromised (compromised dependent on foundation)

Calculate Damage Driving Parameter at DE location

- Interpolate on 3 curves to define trangular distribution of % damage
- Sample distribution – get % damage

Combined Damage Calculation (hard-wired)

Beach-fx
Computational Flow

Year
  Season
    Generate Storm Sequence For Year

For Each Storm
 For Each Profile
  Storm Response Set From SRD
   For Each Reach Using Profile
    Best Lookup in Storm Response Set
    Profile Changes / Wave, Water Level, and Erosion Profiles
    Revise Morphology
    For Each Lot In Reach
     For Each Damage Element In Lot
      Calculate Individual Damages
     Combined Impact

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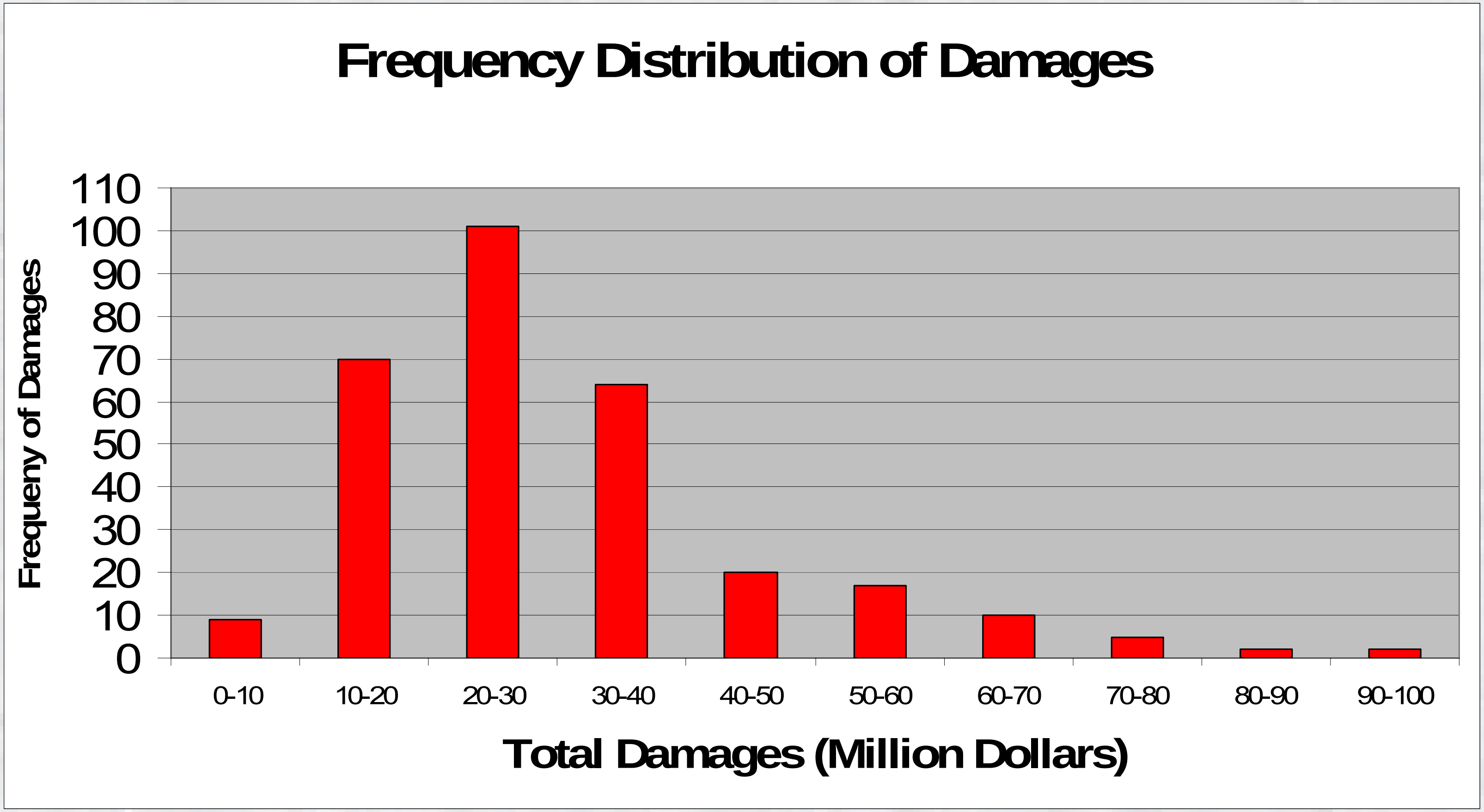
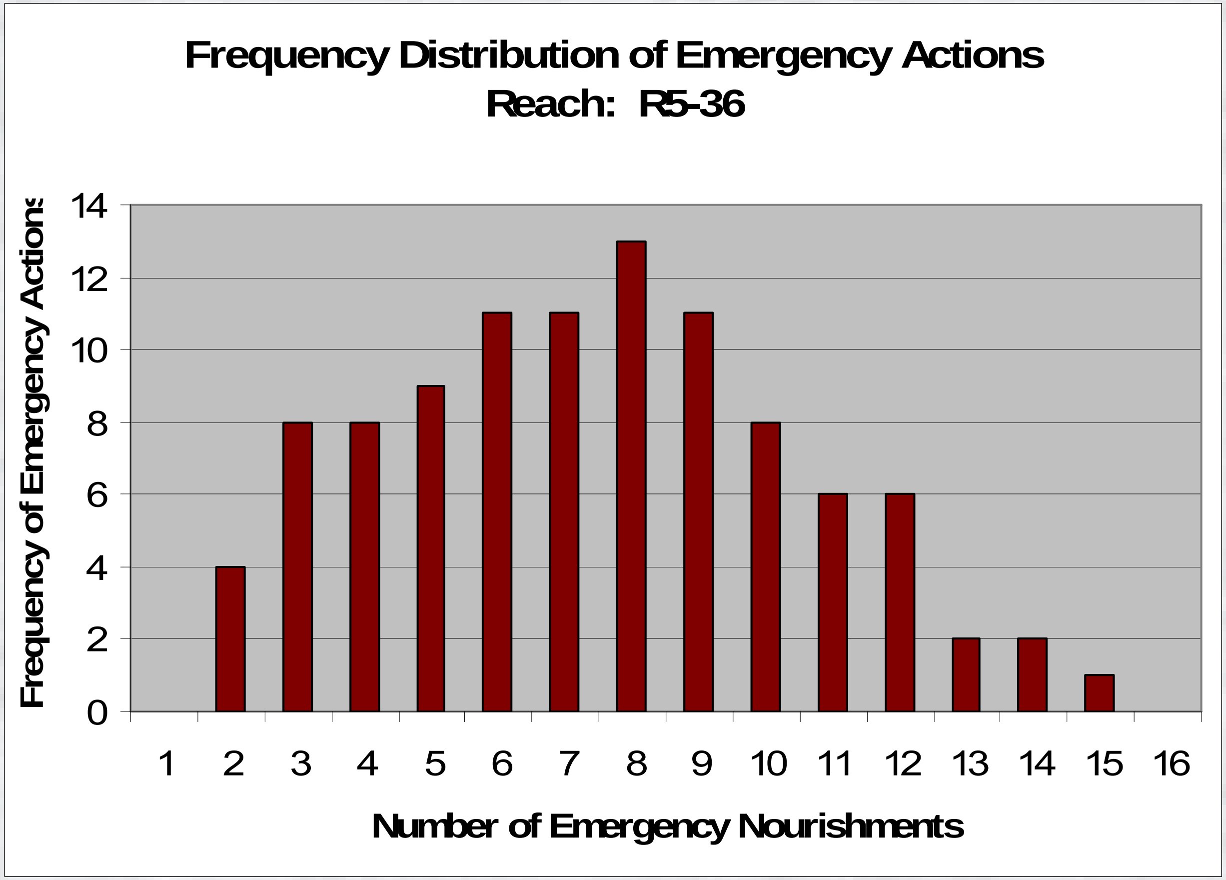
Model Output



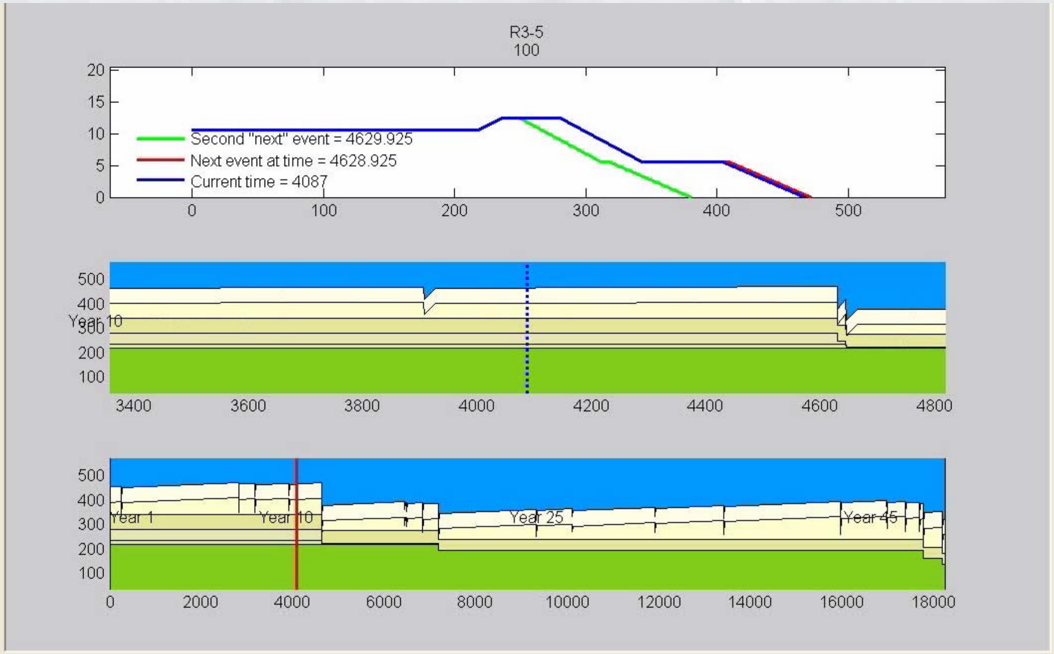
Mean Damages: \$30.3 million δ 16.1
Median Damages: \$27.0 million
90% confidence interval: \$10.9 – \$64.0 million

Beach-*fx* Model Output



Mean Number of Emergency Actions: 6
Median Number of Emergency Actions: 7
90% confidence interval: 3 to 12 Emergency Actions

Beach-*fx*
Limitations



- Simplified Profile
- Simplified Armoring
- Designed for Sandy Beach
- No Wave Attenuation by Structures
- No Breaching / Inlet formation
- Limited application experience